Commissioning of the ATLAS Level-1 Central Trigger

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Abstract

The ATLAS Level-1 Central Trigger consists of the Central Trigger Processor (CTP) and the Muon-to-CTP-Interface (MUCTPI). The CTP receives trigger information from the Level-1 Calorimeter Trigger system directly, and from the Level-1 Muon Trigger systems through the MUCTPI. It also receives timing signals from the LHC machine, and fans them out along with the Level-1 Accept (L1A) signal and other control signals to all sub-detectors. From them, it collects BUSY signals in order to throttle the L1A generation. Upon L1A the Level-1 trigger systems send region-of-interest information to the Level-2 trigger system.

The MUCTPI and CTP crates are already installed in the ATLAS underground counting rooms with final or close-to-final boards. We present their status and discuss first commissioning steps. Particular emphasis is put on the integration of the Central Trigger with the Muon and Calorimeter Trigger systems, the Level-2 trigger, and the readout part of the different sub-detectors.

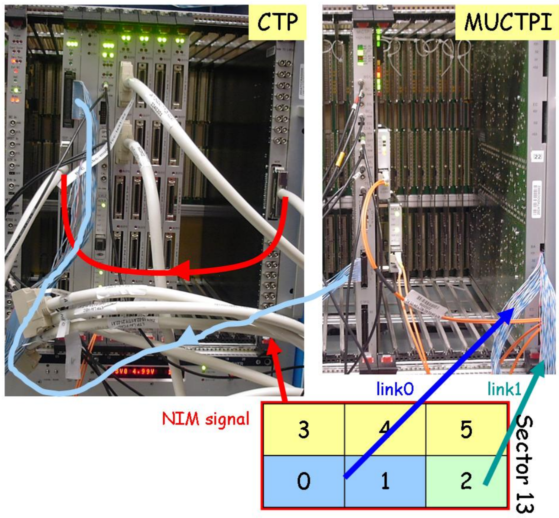

Fig. 1. The CTP and MUCTPI crates installed in the underground counting room. The sketch at the bottom illustrates the connection to the sector 13 barrel muon trigger chambers.

I. Introduction

The ATLAS Level-1 trigger [1] is a system that synchronously processes information from the calorimeter and muon trigger detectors, at the bunch crossing (BC) frequency of 40 MHz. It consists of three parts: the Level-1 Calorimeter Trigger (L1Calo), the Level-1 Muon Trigger (L1Muon), and the Level-1 Central Trigger. The latter consists of the Central Trigger Processor (CTP) [2] and the Muon-to-CTP-Interface (MUCTPI) [3]. The MUCTPI receives muon trigger candidate information at 40 MHz from the barrel muon trigger (RPC) and end-cap muon trigger (TGC) chambers, and subsequently forms muon multiplicities for six different transverse momentum (p_T) thresholds. These data are sent to the CTP as trigger inputs. From L1Calo, the CTP receives electron/photon, tau/hadron and jet candidates as well as global energy information.

From this information the CTP makes the final Level-1 Accept (L1A) trigger decision according to a programmable trigger menu. The L1A is then fanned out to all sub-detectors to initiate readout of the triggered event. In addition, the Level-1 trigger systems send region-of-interest (RoI) information to the Level-2 trigger, and also take part in the combined readout of ATLAS.

In section II we describe the status of the current Central Trigger installation. Section III illustrates the integration tests done with inputs from the L1Calo and L1Muon systems, while section IV is about the commissioning of the Central Trigger system itself. In section V we report on integration tests concerning the distribution of trigger, timing and controls signals to the sub-detectors, the Central Trigger readout and the link to Level-2. Results from cosmic muon data-taking runs with the combined readout of a number of different sub-detectors are discussed in section VI.

II. Status of the Central Trigger Installation

A demonstrator of the MUCTPI and a crate of final CTP modules are already installed in the underground counting room next to the ATLAS experimental cavern. Figure 1 shows the two crates: the CTP crate on the left and the MUCTPI crate on the right. The cabling is explained in section III-B.

The demonstrator version of the MUCTPI provides almost the full functionality of the final system, but misses some flexibility in the handling of overlaps (see [4]). One input board (MIOCT) out of 16 is currently installed, corresponding to one octant in azimuth of one half of the detector. It provides 14 trigger sector inputs (out of 208) to be connected. Currently there are 2 RPC prototype sector logic modules connected (see [5]). In addition to the input boards, the MUCTPI chassis contains the MICTP, MIROD, and MIBAK modules. MIBAK is a custom active backplane used for readout and muon multiplicity summation. The MICTP is responsible for the timing distribution within the crate and for providing muon multiplicities to the CTP. The readout driver MIROD formats the muon candidate data before transmitting them via S-LINK [6] to Level-2 and the readout system.

The CTP crate is installed with final modules only. It contains one input board (CTPIN), receiving up to four trigger signal cables from the Level-1 calorimeter trigger system and the MUCTPI. Two CTPIN boards are yet to be installed. The CTP crate contains in addition the machine interface (CTPMI), the CTPMON, CTPCORE, and 4 CTPOUT boards, a NIM-to-LVDS converter module, and a custom-made backplane. The CTPMI provides the clock and the orbit signals. The CTPMON monitors trigger input signals per bunch crossing identifier. The CTPCORE is responsible for the Level-1 trigger decision based on a configurable trigger menu. In addition, it formats the CTP data to be sent to the readout system and the Level-2 trigger. Finally, the CTPOUT modules fan out the trigger and timing signals to the sub-detectors.

III. Commissioning of Trigger Inputs

Two tests have been performed so far to ensure that the trigger signals are properly received: one with the L1Calo output board, and one with the barrel muon trigger.

A. Level-1 Calorimeter Trigger

An integration test with L1Calo has been performed in July 2006. A final L1Calo Common Merger Module [7], which provides the L1Calo trigger signals to the CTP over a 12 m long cable, was programmed to send a known pattern at 40 MHz to one of the four inputs of the CTPIN. There, the pattern was captured in a memory and compared to the original pattern. A minor firmware issue was discovered in the treatment of parity, but no data transmission errors were found over a period of 15 minutes.

B. Level-1 Barrel Muon Trigger

In sector 13 of ATLAS, 2 barrel middle and 2 barrel outer chambers were fully equipped with cables and services, providing 6 trigger towers with 3 layers of RPC chambers. Their trigger logic provided trigger signals to two prototype sector logic modules, which were connected to the MUCTPI through 2 links: link0 corresponded to tower $0+1$, and link1 to tower 2. A trigger signal (NIM) formed from all 6 towers was separately fed into the CTP via the NIM-to-LVDS board in the CTP crate. The cabling is indicated in Figure 1.

The phase of the clock in the MUCTPI was adjusted with respect to signals sent through link0 and link1 and the clock edge chosen to sample the input signals correctly. The MUCTPI has then successfully sent muon multiplicities to one of the inputs of the CTP.

The NIM trigger signal from the whole of sector 13 was converted into LVDS by the NIM-to-LVDS board in the rightmost slot of the CTP crate (see 1), and then passed to one of the inputs of the CTPIN board. In the CTPIN, the phase with respect to the clock of both the muon multiplicities from the MUCTPI and the NIM trigger signal was measured and the clock edge chosen accordingly. Since the NIM trigger signal did not pass through the MUCTPI, it arrived at the CTP 6 BC

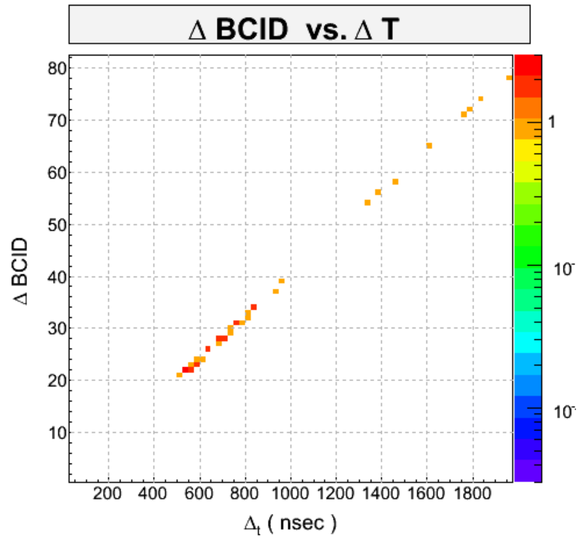

Fig. 2. Correlation of the difference in bunch crossing identifier and time-stamp in the CTP for consecutive events.

earlier, corresponding to the latency of the MUCTPI. It had therefore to be delayed by 6 BC in the CTPIN to be in phase with the muon multiplicities coming from the MUCTPI.

IV. Commissioning of the Central Trigger

The Central Trigger hardware is integrated with the ATLAS Run Control online software [8], a state machine which configures the system through a predefined sequence, in which the system is booted, configured from a configuration database, and brought into the running state. The Central Trigger can already be configured from the trigger database [9], and a simple trigger menu has been chosen for the integration with the muon detectors in sector 13: it consists of the logic OR of:

- at least one muon candidate from the MUCTPI for any p_T threshold
- the sector 13 NIM trigger signal.

The mechanism of assigning a GPS-timestamp to each event accepted by Level-1 was tested as well as the simple deadtime algorithm, which asserts a constant, configurable amount of dead-time after each L1A. Figure 2 shows the correlation between the difference in bunch crossing identifier and time-stamp of two consecutive events. The correlation is perfect, and there are no events with differences smaller than 20 BC (500 ns), which is in accordance with the deadtime settings for this particular run.

Basic monitoring software tools were used to display online the global dead-time and its various contributions, the number of L1As in the CTP and MUCTPI, and the muon multiplicities in the MUCTPI.

V. Commissioning of Trigger Outputs

This section describes the commissioning exercises performed with the trigger outputs, which are of three different types:

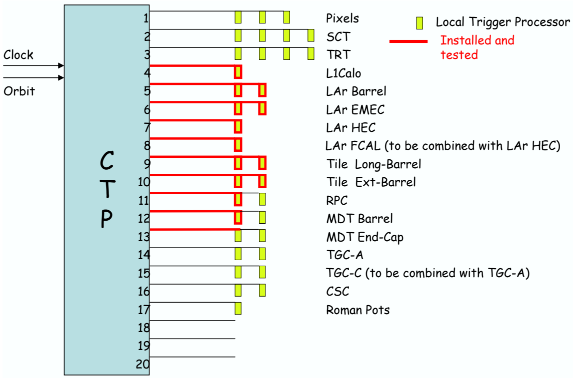

Fig. 3. CTP links to sub-system partitions.

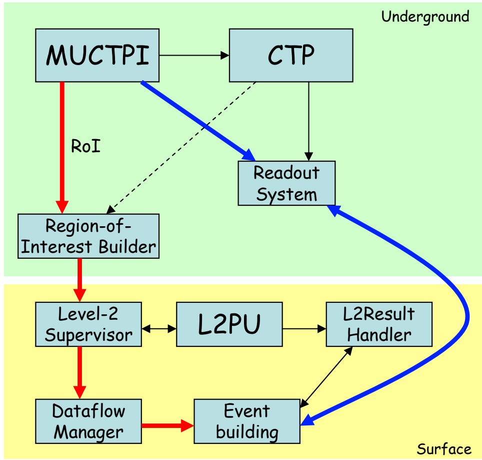

Fig. 4. Setup of the integration tests with the Level-2 trigger.

- trigger, timing and control signals being sent to all sub-detectors,
- readout links, and
- RoI information sent to the Level-2 trigger.

A. Sub-detector trigger, timing and control signals

The CTP supplies all sub-detectors centrally with a common bunch clock and orbit signal, as well as the L1A and other control signals. The bunch clock and orbit signals can either be received from the LHC machine [10], or generated in the CTP for running without beam. The sub-detectors taking part in the combined readout can put back-pressure on the CTP in order to throttle the generation of L1As. This is done via a BUSY signal sent back to the CTP.

The CTP can be connected to 20 sub-systems via differential links with a length typically between 10-30 m. The Local Trigger Processor (LTP) [11] is an interface module used by all sub-detectors to receive the signals from the CTP. In addition, it has the capability of using the signals from local sources such that it can act as a local trigger master, mimicking the CTP. ATLAS is organised in several timing, trigger and control partitions, each corresponding to one LTP and serving a part of a sub-system. Several LTPs can be daisy-chained in order to reduce the number of links to the CTP to below 20. Figure 3 shows the current view on how the CTP will be linked to the various sub-system partitions. Each little box corresponds to an LTP, and the thick lines indicate that the corresponding LTP and cable have already been installed and tested in the underground counting room. This is the case for about half of the links.

The distribution of timing, trigger and control signals to the CTP is done internally in the CTP crate through the backplane. For the MUCTPI, which is located in the neighbouring rack, the signals are distributed directly via LEMO cables.

B. Readout links and readout System

The CTP and MUCTPI send their data through S-LINK mezzanine cards and optical fibres to readout system (ROS) PCs [12] that buffer the Level-1 accepted events. The final readout links and ROS machines are already installed, and a stand-alone integration test has been performed: the MUCTPI was loaded with test input data, which caused the CTP to produce L1As and initiate readout in the CTP and MUCTPI. A temporary event-building PC was retrieving the data fragments from the two ROS PCs over the network, combining and writing them to a single data file on the local disk. Offline, consistency between the MUCTPI and CTP data was found for each recorded event. The rate was limited by temporary event-building to about 25 kHz, proving that the back-pressure mechanisms of the readout systems were fully functional.

C. Level-2 Trigger

For each L1A the MUCTPI and CTP send RoI information via S-LINK to the Region-of-Interest Builder [13] component of Level-2. An integration test has been performed with Level-2, where the MUCTPI data from two complementary streams were compared after event-building. The first stream is the final readout path via the readout system PC, the other one is via the Level-2 trigger path (see Figure 4). The MUCTPI data coming from both paths were found to be consistent for each event and no errors were found. A rate of 20 kHz was achieved, limited by the back-pressure of the reduced subset of the Level-2 trigger system.

VI. Combined Cosmic Muon Runs

Combined cosmic muon runs with several sub-detectors being read out were taken in August 2006. Temporary gas systems were operational in sector 13 for both the barrel muon trigger chambers and the precision muon chambers (MDT). Trigger signals were received from the RPC sector logic as described in section III-B. The sub-systems that took part in the combined readout were the RPC, MDT, the central hadronic calorimeter and the Central Trigger (CTP, MUCTPI).

The timing-in of the different readout chains was done by estimating the signal propagation delays in the electronics and cables, and cross-checking by inspection of the data. The readout window of the RPC was set to 1825-2000 ns (70-80 BC), being in line with the budget of 2000 ns (excluding a 500 ns safety margin) for the total Level-1 latency (from the bunch crossing to the arrival of the L1A signal in the front-end of the sub-detectors). Figure 5 shows the latency contributions from the Central Trigger: the trigger signals from the RPC need 3 BC through the cable to arrive at the MUCTPI, which

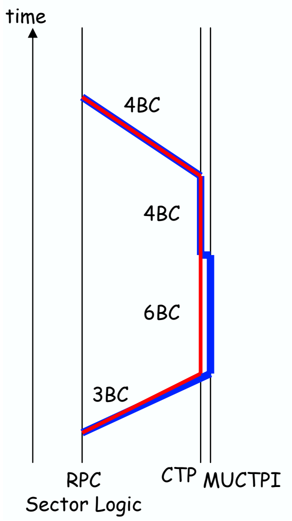

Fig. 5. Space-time diagram of latency contributions by the Central Trigger systems.

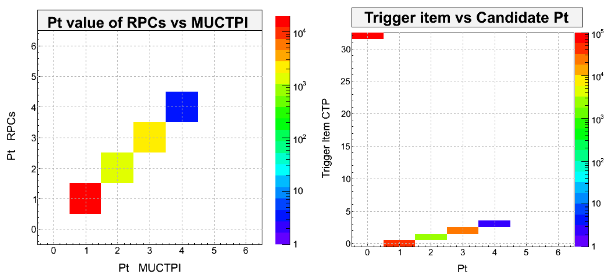

Fig. 6. Left: correlation between the p_T threshold of muon trigger candidates from the MUCTPI and RPC. Right: triggered trigger item number in the CTP versus p_T threshold in the MUCTPI.

takes 6 BC to form muon multiplicities. The multiplicities are further processed by the CTP during 4 clock cycles, before they are sent back to the RPC crate (cable delay of 4 BC). Notice, that the NIM trigger signal arrives directly at the CTP and is therefore delayed by 6 BC (MUCTPI latency) to be in time with the arrival of the multiplicities from the MUCTPI. Both the MUCTPI latency of 6 BC and the CTP latency of 4 BC are within the latency budget required for these systems.

About 500'000 events have been recorded with a rate between 40 and 60 Hz, depending on the configuration of the barrel muon trigger system. Subsequent offline data analysis showed many different correlations between the various sub-detectors: Figure 6 shows, for instance, on the left the p_T of muon candidates as seen in the RPC readout data, correlated with the information as seen in the MUCTPI data. The right picture shows the p_T of muon candidates in the MUCTPI readout data in correlation with the triggered trigger item number in the CTP readout data. As expected, the thresholds 1, 2, 3, and 4 are correlated with trigger items 0, 1, 2, 3, while no candidate (threshold 0) corresponds to trigger item 32. The latter are events where the NIM trigger signal is present, but no muon trigger candidate was found.

VII. Conclusions

The Level-1 central trigger systems CTP and MUCTPI are installed and functional in the ATLAS underground counting room, with mainly final hardware. A complete trigger and readout chain has been successfully operated in the cavern with cosmics, where the CTP triggered on signals from the barrel muon trigger system (sector 13). The RPC, MDT, central hadronic calorimeter, CTP and MUCTPI took part in the subsequent combined readout, whose recorded events were analysed and found consistent. First integration tests with the Level-2 system and the Level-1 calorimeter trigger have been successfully performed.

Acknowledgements

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